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For

A TUNABLE NARROW BAND OPTICAL FILTER

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A TUNABLE NARROW BAND OPTICAL FILTER

FIELD OF THE INVENTION

[001] This invention generally relates to optical components such as an optical monitoring device. More particularly this invention relates to tunable optical bandpass filters.

BACKGROUND OF THE INVENTION

[002] It is essential to monitor optical signals for highly reliable WDM systems. However, it becomes difficult to resolve each individual optical channel for power measurement because the individual channel spacing in DWDM systems decreases in order to increase transmission capacity. A very narrow band optical filter may be used to extract one channel in the DWDM signals. Bulk optic narrow band optical filters typically require advanced technologies and are typically expensive.

[003] Bulk optic narrow band optical filters exist that use a Fabry Perot filter having movable mirrors. The movable mirrors cause resonant frequency changes in the optical signal. These narrow band optical filters may create a transmission spectrum narrow enough to extract one channel of a DWDM filter for analysis. The construction of these precise movable mirrors is typically expensive and the filter may have high insertion losses.

[004] All-fiber optical filters typically have lower insertion losses on the optical signal than bulk optic filters. Most all-fiber optical filters, however have a bandwidth of a wide band tunable filter that is usually several nanometers. The corresponding transmission

response is an order of magnitude wider than that of the required bandwidth for performance monitoring of the DWDM signal.

[005] All-fiber type filters typically employ a filtering effect using the relation between modes of light propagating in an optical fiber. In principle, a light wave propagates through the core of optical fiber as the light wave totally reflects at an interface between the core and cladding of the optical fiber. On the other hand, the light wave has difficulty in propagating through the cladding of the optical fiber because the jacket surrounding the cladding is highly absorptive and its refractive index is higher than that of the cladding, which causes strong attenuation.

[006] If the jacket is stripped -- that is, if the cladding is exposed in the air -- the light wave can propagate farther because the light wave is totally reflected at the interface between the cladding and air due to the higher refractive index of the cladding than that of air.

[007] The mode for a light wave that propagates satisfying the total reflection condition at the interface of core and cladding may be referred to as a "core mode." The mode for a light wave that propagates satisfying the total reflection condition at the boundary surface of cladding and surrounding air, while failing to satisfy the total reflection condition at core/cladding interface, is called "cladding mode."

[008] In core mode, most of the energy of the optical signal is distributed in the core. In cladding mode, most of the energy of the optical signal is distributed in the cladding.

SUMMARY OF THE INVENTION

[009] Various methods, apparatuses, and systems are described for routing an optical signal through the optical filter multiple times.

[0010] Other features and advantages of the present invention will be apparent from the accompanying drawings and from the detailed description that follows below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The present invention is illustrated by example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:

Figure 1 is a block diagram of an embodiment of an acousto-optical filter tunable bandpass filter aligned to facilitate multiple passes of an optical signal through the bandpass filter;

Figure 1b is an exemplary graph illustrating a transmission spectrum developed after a first pass through the tunable bandpass filter and the reduced transmission spectrum developed by the tunable bandpass filter after multiple passes through the tunable bandpass filter;

Figure 2 is a magnified view of an embodiment of the interaction region containing light absorbing material blocking various wavelengths of the optical signal in the core of the optical waveguide;

Figure 3 is a block diagram of an embodiment of an optical filter having two or more reflectors aligned to reflect the optical signal bi-directionally through the interaction region;

Figure 4 is a block diagram of an embodiment the two or more reflectors that are aligned to reflect the optical signal in a unidirectional path multiple times through the interaction region;

Figure 5 is a graph of an exemplary transmission spectrum of the an embodiment of the tunable bandpass filter;

Figure 6 is a block diagram of an embodiment or two or more reflectors aligned to reflect a portion of the optical signal between the reflectors multiple times;

Figure 7a is a block diagram of an embodiment of the acousto-optical tunable narrow band filter generating the amplitude and the frequency of an acoustic wave in order to control the attenuation on the corresponding optical center wavelength;

Figure 7b is a graph illustrating the transmission through the acousto-optic filter for a first acoustic wave having a first amplitude and a second acoustic wave having a second lesser amplitude generated by the acoustic wave exciter;

Figure 8a is a block diagram of an embodiment of multiple cascaded acoustic wave exciters transmitting multiple acoustic waves to shape the transmission response of the optical signal passed through the bandpass filter;

Figure 8b is a graph of multiple acoustic waves each having discrete amplitudes and discreet frequencies applied to the cascaded interaction region to shape the transmission response of an optical signal passing through the cascaded interaction regions;

Figure 8c is a graph of an exemplary transmission spectrum shaped by the application of the multiple acoustic waves;

Figure 9 is a graph of an exemplary narrow band transmission spectrum such as 1555 nm, shaped by a control component synchronizing the application of multiple acoustic waves; and

Figure 10 is a block diagram of an embodiment of an optical monitoring device using an embodiment of the tunable bandpass filter.

DETAILED DESCRIPTION

[0012] In general, one or more methods and apparatuses herein describe receiving an optical signal in an optical filter and routing the optical signal through the optical filter multiple times. Reflecting the optical signal multiple times narrows the transmission spectrum developed by the bandpass filter. The signal strength of the optical signal reduces with each pass through the bandpass filter. If a transmission spectrum under analysis is narrow enough, then, for example, optical characteristics of individual DWDM channels may be precisely measured. Further, one or more methods and apparatus herein describe selectively removing wavelengths from an optical signal via coupling by applying acoustics waves to induce the coupling. Further, many other methods and apparatuses herein describe developing a given transmission spectrum in an optical filter. For one embodiment, coupling means transitioning energy from one spatial propagation mode to another spatial propagation mode.

[0013] Figure 1a is a block diagram of an embodiment of an acousto-optical filter tunable bandpass filter aligned to facilitate multiple passes of a band of wavelengths within the optical signal through the bandpass filter. For one embodiment, the tunable narrow-band bandpass filter **100** may include an optical signal input **102**, an acoustic wave exciter **104**; an optical waveguide **106** having an interaction region **108**, two or more reflectors, such as first reflector **130** and a second reflector **112**, aligned to facilitate multiple passes of the band of wavelengths within the optical signal through the interaction region **108**. The tunable narrow-band bandpass filter may further include light-absorbing material **110** such as a core blocker, interposed between the first reflector **130** and the second reflector **112**, and an optical signal output **114**. Further, the tunable

bandpass filter **100** may include one or more acoustic wave absorbers **116** connected to the interaction region **108** and a heat sink **118** connected to each acoustic wave absorber **116**.

[0014] For one embodiment, the acoustic wave exciter **104** may comprise a propagation member **120** such as a horn, an acoustic wave generator **122** such as a transducer, and a signal generator **124** such as an RF signal generator. For one embodiment, the signal generator **124** applies an RF signal to the acoustic wave generator **122.** The acoustic wave generator **122** generates an acoustic wave through the propagation member **120**. The acoustic wave exciter **104** generates the acoustic wave at a first frequency that corresponds to a first center optical wavelength. The propagation member **120** amplifies and transmits the acoustic wave to vibrate the interaction region **108.**

[0015] Figure 2 is a magnified view of an embodiment of the interaction region containing light absorbing material blocking various wavelengths of the optical signal in the core of the optical waveguide. For one embodiment, the optical waveguide **206** may have a core **201**, a cladding **203**, and optionally a structural protective casing such as a jacket **205**. For one embodiment, the interaction region **208** in the optical waveguide is where the jacket **205** is removed. The removal of the jacket minimizes damping vibration of the interaction region **208** caused by the vibration of the acoustic wave. The interaction region **208** may have a first portion **209** and a second portion **211**. The acoustic wave propagates as a traveling flexural wave along the interaction region **208**. The periodic microbend effects induce antisymmetric refractive index changes in the interaction region **208** of the optical waveguide **206**.

[0016] Figure 1b is an exemplary graph illustrating a transmission spectrum developed after a first pass through the tunable bandpass filter and the reduced transmission spectrum developed by the tunable bandpass filter after multiple passes through the tunable bandpass filter. Referring to Figures 1a and 1b, the interaction region **108** receives the optical signal such as a light wave. The propagation member **120** transmits the acoustic wave at a particular frequency to the interaction region **108**. The acoustic wave exciter **104** causes a band of optical wavelengths centered around the first center optical wavelength **126** in the optical signal to couple from a first mode such as a core mode to a second mode, such as a cladding mode, in the optical waveguide **106**. The band of desired optical wavelengths within the transmission spectrum **128** couples to the second mode while the undesired optical wavelengths remain in the first mode. The light absorbing material **110** absorbs the energy of the optical signal in the first mode, thereby eliminating the undesired optical wavelengths that are not within the transmission spectrum **128**.

[0017] Referring to Figure 2, the optical signal **207** may contain multiple discrete optical wavelengths, such as a first optical wavelength at 1550 nanometers (nm) **213**, a second optical wavelength at 1554 nm **215**, and a third optical wavelength at 1555 nm **217**. The acoustic wave exciter **104** applies the acoustic wave to couple the desired center optical wavelength of 1550 nm **213** from the core mode to the cladding mode in the first portion **209** of the interaction region **208**. The second optical wavelength **215** and third optical wavelength **217** have wavelength values that are outside the band of wavelengths affected by the acoustic wave. Thus, the second optical wavelength **215** and third optical wavelength **217** continue to propagate through the core **201** and are absorbed

by the light absorbing material **210** located in the core **201**. In contrast, the first optical wavelength **213** propagates in the cladding **203** past the light absorbing material **210** located in the core **201** to a second portion **211** of the interaction region **208**. A reflector **212** exists at both ends of the interaction region **208** to facilitate multiple passes of the optical signal **207** through the interaction region **208**. The forward traveling first optical wavelength **213** strikes the reflector **212** and propagates through the interaction region again in the backward direction. Note only the second reflector **212** is illustrated in Figure 2 in order to eliminate confusion in the drawing.

[0018] Referring to Figure 1a, the interaction region **108** may include the first portion **109** and the second portion **111**. The light absorbing material **110** may be interposed between the first portion **109** of the interaction region **108** and the second portion **111** of the interaction region **108**. The length of each portion **109, 111** of the interaction region **108** may be based upon the optical wavelength spectrum of the optical signal, the frequency of the acoustic wave, and the type of the fiber. The length of the first portion **109** of the interaction region is such that the optical signal when exposed to the acoustic wave causes the desired optical wavelength signal to couple from the first mode to the second mode prior to reaching the location of the light absorbing material **110**. Further, the length of the second portion **111** of the interaction region **108** is such that the desired optical wavelengths when exposed to the acoustic wave causes the desired optical wavelengths to couple back from the second mode to the first mode after propagating past the location of the light absorbing material **110**. For one embodiment, the initial range of wavelengths within the transmission spectrum after the first pass of the optical signal through the interaction region is proportional to the length of each portion **109, 111**.

[0019] The first reflector **130** and the second reflector **112** are aligned to reflect the desired band of wavelengths bidirectionally through the interaction region **108**, the acoustic wave, and the light absorbing material **110** multiple times. The first reflector **130** and second reflector **112** may have a reflectivity less than one hundred percent. The optical signal is reflected between the first reflector **130** and second reflector **112** through the interaction region **108** to increase the Q of the bandpass filter and narrow the transmission spectrum of the optical wave lengths that are passed through the bandpass filter.

[0020] Referring to Figure 1b, after each pass through the bandpass filter the transmission spectrum **128** of optical wavelengths that are passed narrows. Eventually, after multiple passes through the interaction region, the remaining optical signal retains the same center optical wavelength **126** with a very narrow transmission spectrum, such as the second transmission spectrum **132.** Thus, a very precise discrete range of optical wavelengths may be developed and thus analyzed within a wide band of optical wavelengths.

[0021] Referring to Figures 1a and 1b, the first center optical wavelength **126** is proportional to frequency of the acoustic wave generated by the signal generator **124**. Therefore, the acoustic wave exciter **104** may adjust the radio frequency generated by the signal generator **124** in order to select the desired center optical wavelength **126** in the optical signal that is to be coupled from the first mode to the second mode.

[0022] Referring to Figure 1a, the one or more acoustic wave absorbers **116** absorb the vibrational energy of the acoustic wave to stop the microbend effects on the optical waveguide **106**. The heat sink **118** connected to each acoustic wave absorber **116**

dissipates the excess energy generated by the vibrational energy, if needed. After the multiple passes develop the discrete optical wavelength, the small percentage of the optical signal that is not reflected back into the interaction region **108** may be collected as the output signal from the tunable bandpass filter **100**.

[0023] Figure 3 is a block diagram of an embodiment of an optical filter having two or more reflectors aligned to reflect the optical signal bidirectionally through the interaction region. For one embodiment, the two or more reflectors such as the first reflector **330** and the second reflector **312**, are aligned to reflect the optical signal bidirectionally through the interaction region **308** multiple times.

[0024] As noted above, the first reflector **330** reflects less than hundred percent of the optical wavelengths to narrow the spectrum of wavelengths contained within the optical signal. The reflection of the optical signal starts the multiple pass process to develop a very precise and narrow transmission spectrum. For one embodiment, the two or more reflectors **312, 330** route the optical signal through the interaction region **308** multiple times, such as twenty-five times. For one embodiment, the effective bandwidth of the transmission spectrum of the tunable bandpass filter is $1/N^{1/2}$ times that of the bandpass filter for the first pass of the optical signal through the interaction region **308**, where N is the number of times the optical signal propagates through the interaction region **308**. The maximum number of passes through the tunable bandpass filter **300** depends on the insertion loss that occurs while traveling through the tunable bandpass filter **300**.

[0025] Figure 4 is a block diagram of an embodiment of two or more reflectors that are aligned to reflect the optical signal in a unidirectional path multiple times through the interaction region. For one embodiment, the narrow band bandpass filter **400** may

contain a first reflector **430**, a second reflector **412**, a third reflector **415**, a fourth reflector **417**, and light absorbing material **410**.

[0026] The entering optical signal may propagate through the first reflector **430**. A band of desired optical wavelengths in response to the effect of the acoustic wave on the optical waveguide couple from the first mode to the second mode in the interaction region **408**. The band of desired optical wavelengths propagate in the second mode past the light absorbing material **410** while the unaffected wavelengths are absorbed. The second reflector **412**, third reflector **415** and fourth reflector **417** reflect the band of desired optical wavelengths at an angle to route the optical signal back to the first reflector **430**. The first reflector **430** then reflects the band of desired optical wavelengths through the interaction region **408** again. The optical signal reflects this way through the tunable bandpass filter **400** multiple times to narrow the transmission spectrum of the band of wavelengths to a desired bandwidth of optical wavelengths. When the desired transmission spectrum is developed, then a small percentage of the optical signal which is not reflected toward the light absorbing material **410** by the first reflector **430** is collected as the output signal **421** of the tunable bandpass filter **400**. This output signal **421** containing the narrow transmission spectrum may be supplied to analytical components to determine optical characteristic of that transmission spectrum.

[0027] In an alternate embodiment, the optical signal propagates through multiple cascaded interaction regions to develop the narrow transmission spectrum rather than being reflected to make multiple passes through the same interaction region **408**. The number of cascaded interaction regions depends on the insertion loss and the loss in the optical waveguide.

[0028] Figure 5 is a graph of an exemplary transmission spectrum of the tunable bandpass filter. Vertically, the graph illustrates power level loss **502** in decibels of various optical wavelengths in the optical signal. The range of the power level loss **502** spans from 0 dB loss to minus 40 dB loss. The highest power level represented on the graph, 0 dB loss, corresponds to the optical signal strength after the first pass through the interaction region. Horizontally, the graph illustrates the transmission spectrum **504** of the optical wavelengths from the optical signal developed in the bandpass filter. The range of the transmission spectrum **504** spans from 192.9 Terahertz to 193.1 Terahertz. The center optical wavelength **506** being at 193.0 Terahertz and full optical power (i.e. 0 dB).

[0029] The dotted line represents the first transmission spectrum **508** of the bandpass filter after the first pass through the interaction region. In this example, the bandpass tunable filter has a Gaussian shape with e-1 width of 200 GHz. Thus, the first transmission spectrum **508** has a width at minus 3dB **510** of approximately 333GHz .

[0030] The solid line represents the second transmission spectrum **512** after multiple passes through the interaction region. Each optical wavelength within the second transmission spectrum **512** has a free spectral range of 5 GHz and the envelope of the second transmission spectrum **512** is about 17 GHz at minus 3 dB **510**. Thus, only a band of 17 GHz of optical wavelengths remain in the second transmission spectrum **512** that have a signal power level of greater than a minus 3 dB. The transmission spectrum **504** decreased from 333GHz at minus 3 dB **510** to 17 GHz at minus 3 dB **510**. The transmission spectrum **504** passed by the bandpass filter after multiple passes through the interaction region has reduced by a factor of about 11.

[0031] Note, in this example, the reflectivity of the reflectors may be approximately 95 %. If the reflectivity of the reflectors is set to 98%, then the transmission spectrum **504** may be reduced by a factor of 20 after multiple passes through the interaction region. The reflectivity at less than 100% allows the undesired optical wavelengths at or outside the cutoff frequencies to be eliminated and the Q of the filter to increase. For one embodiment, wavelengths other than the center optical wavelength decrease in signal strength by a factor proportional to the square root of their original signal strength after each pass through the interaction region. For one embodiment, the transmission spectrum **512** of the acoustical optical tunable filter is less than 18 Gigahertz.

[0032] For one embodiment, when the reflectors, comprising a Fabry-Perot cavity, reduce the bandwidth of the wide band tunable filter, 3 dB bandwidth of the transmission spectrum **512** is given by:

Δf_{3dB} = Bandwidth of the wide band filter at $\Delta\alpha = 10 \log e \ * (1\text{-}r)/r$,

where r is intensity reflectivity of the reflector and $\Delta\alpha$ is the loss in dB of the wide band filter for bandwidth calculation. The formula may assume the loss of the wide band filter is 0 dB at the transmission peak and both reflector s have the same reflectivity $r \sim 1$.

[0033] For one embodiment, a Gaussian wide band filter, 3 dB bandwidth of the band width of the transmission spectrum **512** is given by:

$$\Delta f_{3dB} = \Delta f_e \, [(1\text{-}r)/r]^{1/2} /2,$$

where Δf_e is the e^{-1} bandwidth of the wide band a Gaussian filter.

[0034] Various other configurations and implementations exist. For one embodiment, the two or more reflectors may be any combination of Fiber Bragg Gratings, mirrors,

couplers, recirculator, or similar component to direct the optical signal in a specific direction. For one embodiment, the optical waveguide may be polarization preserving fiber. For one embodiment, the optical wave-guide comprises a single mode optical fiber. For an alternative embodiment, the optical waveguide may be a multi-mode fiber. For one embodiment, the optical wave-guide is planar in shape. For one embodiment, the light absorbing material can similarly be light scattering material such as a fiber Bragg grating aligned to reflect selected wavelengths at an angle out of the core. The optical waveguide may have multiple modes of traveling within the optical waveguide such as core-to-core, core-to-cladding, polarization-to-polarization, multiple cladding mode to a single core mode, and other similar optical modes.

[0035] Figure 6 is a block diagram of an embodiment with two or more reflectors aligned to reflect a portion of the optical signal between the reflectors multiple times. The tunable bandpass filter comprises two or more reflectors such as a first reflector **602** and a second reflector **604**, an input light signal **606,** and an output light signal. The two or more reflectors, such as Fiber Bragg gratings, may be tunable to a band of optical wavelengths by thermally or mechanically compressing the Fiber Bragg gratings. Each reflector **602, 604** may possess a reflectivity of less than one hundred percent reflectivity. The first reflector **602** and the second reflector **604** may reflect the center wavelength and a band of wavelengths around the center wavelength, i.e. the transmission spectrum, back and forth between the first reflector and the second reflector multiple times. Each time the transmission spectrum is reflected the band of wavelengths within that transmission spectrum above a given signal strength such as minus 3 dB, narrows due to the reflection loss and the insertion loss associated with the traveling through the bandpass filter. Due

to the reflection loss, the wavelengths that possess wavelength valves other than the center optical wavelength decrease significantly in signal strength. Signal strength may be measured in terms of optical power, intensity or amplitudes of the optical wavelength. For one embodiment, the percentage of the optical signal that is not reflected by the second reflector **604** may be collected as the output optical signal.

[0036] Figure 7a is a block diagram of an embodiment of the acousto-optical tunable narrow band filter generating the amplitude and the frequency of an acoustic wave in order to control the attenuation on the corresponding optical center wavelength. The tunable narrow band filter may include one or more acoustic wave exciters **702**, an optical waveguide **704** having an interaction region **706**, an optical signal input, and an optical signal output **710**.

[0037] The acoustic wave exciter **702** may select the band of wavelengths in the optical signal to be effected and also the amount of attenuation on the signal strength of those wavelengths. For one embodiment, the acoustic wave exciter **702** may adjust the radio frequency generated by the signal generator **712** in order to select the desired center optical wavelength in the optical signal that is to be coupled from the first mode to the second mode. In this case, the acoustic wave exciter **702** also acts as a variable attenuator on the center wavelength by adjusting the amplitude of the radio frequency signal driving the acoustic wave generator **708**. Depending upon the amplitude of the acoustic wave transmitted to the interaction region **706**, a percentage of the corresponding center optical wavelength and the band of wavelengths surrounding the center wavelength couple from the first mode to the second mode. If the optical signal is obtained from the first mode,

then all portions of the wavelengths diverted to the second mode will have in effect been attenuated from the optical signal.

[0038] Figure 7b is a graph illustrating the transmission through the acousto-optic filter for a first acoustic wave having a first amplitude **714** and a second acoustic wave **716** having a second lesser amplitude generated by the acoustic wave exciter. As noted above, the greater the amplitude, such as V1, of the acoustic wave transmitted to the interaction region, the greater percentage of the corresponding center optical wavelength and the band of wavelengths surrounding the center wavelength couple from the first mode to the second mode. The frequency of the acoustic wave, such as f1 or f2, determines the center wavelength in the optical signal coupled by the acoustic wave.

[0039] Either the same acoustic wave exciter or two or more acoustic wave exciters working in conjunction may generate the multiple acoustic waves. Multiple radio frequency ("RF") signals may be applied by one or more signal generators to the acoustic wave generator in order to generate the multiple acoustic waves at different frequencies, such as the first acoustic wave **714** and the second acoustic wave **716**, from the same acoustic wave exciter. Multiple acoustic wave exciters may generate a set of acoustic waves at N number of frequencies that corresponds to N number of optical wavelengths. For example, the multiple acoustic wave exciters may generate the first acoustic wave **714** and the second acoustic wave **716**. Each acoustic wave in the set of acoustic waves having an amplitude that correlates to a determinable amount of reduction of optical power in the N number of optical wavelengths. The acoustic waves **714, 716** cause the corresponding band of optical wavelengths within the optical signal to couple from a first mode, such as the core mode, to the second mode, such as the cladding mode.

[0040] Figure 8a is a block diagram of an embodiment of multiple cascaded acoustic wave exciters transmitting multiple acoustic waves to shape the transmission response of the optical signal passed through the bandpass filter. For one embodiment, a series of acoustic wave exciters **802** may each be connected to discrete interaction regions **804, 806, 808** in a cascaded manner. Each acoustic wave exciter **802** transmits an acoustic wave at a frequency different that the other acoustic waves.

[0041] Figure 8b is a graph of multiple acoustic waves each having discrete amplitudes and discreet frequencies applied to the cascaded interaction region to shape the transmission response of an optical signal passing through the cascaded interaction regions. Each acoustic wave at its own frequency corresponds to particular center wavelength in the optical signal such as a first center optical wavelength **810**, a second center optical wavelength **812**, a third center optical wavelength **814**, a fourth center optical wavelength **816**, and a fifth center optical wavelength **818**.

[0042] 8c is a graph of an exemplary transmission spectrum shaped by the application of the multiple acoustic waves. Referring to figures 8b and 8c, the multiple acoustic waves **810, 812, 814, 816, 818** may be used to shape the transmission spectrum **820** of optical wavelengths passed by the bandpass filter. For example, as illustrated, the transmission spectrum **820** consists of a band of wavelengths from approximately 1530 nm to 1560 nm that passed by the tunable bandpass filter. The transmission spectrum **820** having a customized asymmetric shape formed by the cumulative attenuation caused by the application of the multiple acoustic waves **810, 812, 814, 816, 818** to the one or more interaction regions in which the optical signal travels through.

[0043] Referring to figures 8a, 8b, and 8c, a control component such as a software program may synchronize transmitting the multiple acoustic waves **810, 812, 814, 816, 818** to the one or more interaction regions **804, 806, 808** in order to shape the signal strength and optical wavelengths passed by the bandpass filter **800**. The one or more acoustic wave exciters **802** generate multiple band rejection responses that sweep a bandpass of wavelengths across a wavelength spectrum to create a transmission spectrum **820**. The tuning can move the transmission spectrum **820** of the optical signal in a step fashion to sweep individual wavelengths within the optical signal. For example, the control component may synchronize the acoustic waves to create transmission spectrum of 1530 nm to 1540 nm. Next, the control component may synchronize the acoustic waves applied to the interaction regions **804, 806, 808** to generate a transmission spectrum **820** of 1540nm to 1550 nm.

[0044] For an alternative embodiment, a first acoustic wave exciter (not shown) and a second acoustic wave exciter couple to the same interaction region rather than cascading the acoustic wave exciters.

[0045] Figure 9 is a graph of an exemplary narrow band transmission spectrum such as 1555 nm, shaped by a control component synchronizing the application of multiple acoustic waves. The effects of a first acoustic wave **902**, a second acoustic wave **904**, a third acoustic wave **906,** and a fourth acoustic wave summed together may shape a narrow band transmission spectrum **910** of approximately 1554.5 nm to 1555.5 nm. Once the 1555 nm wavelength is developed and collected in the output signal for monitoring purposes, then the control component may generate synchronized acoustic waves to shape a narrow band transmission spectrum of, for example, approximately 1556 nm. Thus, the

tuning can move the transmission spectrum **910** of the optical signal in a step fashion to sweep individual wavelengths within the optical signal.

[0046] For one embodiment, the tunable bandpass filter is virtually polarization independent because coupling the optical wavelengths in the optical signal through vibrating the optical waveguide causes less than two tenths of a decibel reduction in the optical signal due to polarization effects on the optical signal.

[0047] Figure 10 is a block diagram of an embodiment of an optical monitoring device using an embodiment of the tunable bandpass filter. The optical monitoring device **1002** may be an optical power monitor, a spectral analyzer, or similar device. The optical monitoring device **1002**, such as a spectrum monitoring device, may be located after a second gain block **1004** in order to determine characteristics of the optical signal and characteristics of the transmission spectrum developed within the bandpass filter. The transmission spectrum may contain characteristics such as optical signal strength, noise level, drift of the wavelengths from nominal, and other similar characteristics.

[0048] Optical monitoring device **1002** uses an embodiment of the tunable bandpass filter to obtain a precise representation of discreet wavelengths, such as 1555 nm, within a narrow band of wavelengths, such as 1550 nm to 1560nm, in order to determine optical characteristics of the particular wavelength. The control component may then sweep the narrow band of wavelengths to determine the optical characteristics for each discrete wavelength within that narrow band. Once those optical characteristics have been determined, then the optical monitoring device **1002** may provide feedback to first gain block **1006** in order to correct any of those characteristic deviating from their desired set point. The optical monitoring device **1002** may determine the characteristics of the

wavelength in a given range of wavelength such as 1530 nm to 1560 nm in order to provide feedback to flatten the gain within that range of wavelengths.

[0049] For alternative embodiments, most functions performed by electronic hardware components may be duplicated by software emulation.

[0050] In the forgoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set fourth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustration rather then a restrictive sense.